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Method of Carrying out Continuous Preparation Processes on Tightly  
Meshing Extruders Rotating in the same Sense

**Specification**

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The invention relates to a method of carrying out continuous preparation processes on tightly meshing extruders rotating in the same sense such as twin-screw and multi-shaft screw-type extruders.

- 10 Tightly meshing twin-screw and multi-shaft screw-type extruders rotating in the same direction are used for continuous kneading processes with or without melting. Frequently, continuous degassing, mixing and expanding processes are integrated, too, and there are cases when the extruders are also used for reactions.

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The products to be processed comprise plastics, resins, liquids, viscoplastic fluids, pulverulent and fibrous additives as well as food compounds. Discharging may take place for instance via filters and molding processes such as pelletization and section extruding.

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Extruders of the type mentioned at the outset have been known, in which the screw diameter amounts to as much as 340 mm. The throughputs range from 5,000 to 35,000 kg/h at a ratio between the screw outer diameter and screw inner diameter ( $D_a/D_i$ ) of 1.18 to 1.25 and 1.4 to 1.6, respectively.

- 25 The ratio between torque and center distance<sup>3</sup> of axes ( $m_d/a^3$ ) - the so-called "torque density" - is in the range of 5 to 10. Depending on the size of the extruders, speeds of rotation are run, ranging from 200 to 500 rpm - in exceptional cases even up to 600 rpm.

Customarily, the design of the extruders is based on the principle of geometric and torque related similarity. Geometric similarity exists when the ratio  $D_a/D_i$  is constant; torque related similarity exists when the ratio  $M_d/a^3$  is constant.

In addition to melt temperature and dwell time, the shear rate within the screw root filled with melt is another decisive factor for the dispersing, mixing and homogenization grade of the processed product.

In many processes the mixing, dispersing and homogenization grade will be the higher, the higher the shear rate. In today's state of extruder engineering, mean shear rates in the melting range of between 20 to 150 1/sec and mean product dwell times in the entire screw range of between 15 to 60 sec are customary in standard preparation processes.

In conventional extruders, the mean shear rates are restricted upwards by the screw speed of rotation and the so-called "volumetric ratio" represented by the ratio  $D_a/D_i$ . However, increasing shear rates are accompanied with higher specific values of the energy supplied, which may lead to inacceptably high melt temperatures. Together with high average dwell times of the product in the extruder, this may lead to quality reducing deterioration of the product in terms of thermal decomposition and cross-linking.

It is the object of the invention to put into practice quality increasing mean shear rates in the range of up to  $\geq 1,000$  1/sec accompanied with simultaneous reduction of the duration of action of temperature peaks in the product without possible occurrence of the difficulties described above.

This object is attained by the extruder being operated at a screw speed of rotation of at least 800 rpm while the so-called "torque density" ( $M_d/a^3$ ) which can be induced is simultaneously increased by at least 11 Nm/cm<sup>3</sup> and the volumetric ratio ( $D_a/D_i$ ) is at least 1.5.

With the increased torque density ( $M_d/a^3$ ) selected according to the invention of at least 11 Nm/cm<sup>3</sup>, the extruder can easily be operated at the high screw speeds of rotation without any inadmissibly high specific energy input resulting. Another advantage resides in a very high product throughput per time unit.

Suitably, the dwell time of the product in the extruder is less than 10 seconds.

In keeping with another embodiment of the invention, the extruder is operated at a screw speed of rotation of up to 3,000 rpm, while the so-called "torque density" ( $M_d/a^3$ ) that can be induced is increased by up to 15 Nm/cm<sup>3</sup> and the volume ratio is greater than or equal to 1.55 and the mean product dwell time is less than 2 seconds. This will give especially short (mean) dwell times of the product in the extruder as a result of the high throughputs then possible.

The short product dwell times of 1 to 10 sec resulting from the high screw speeds of rotation and the high product throughputs simultaneously reduce the tendency toward thermal decomposition or cross-linking of the products.

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Within certain limits, an increase of the screw speed of rotation is also possible without an increase of the torque density ( $M_d/a^3$ ). However, the maximum screw speed of rotation is limited by the maximum upper limit of specific energy input which exists in every process and corresponds to the maximally permissible melt temperature (without deterioration of the product occurring).

The embodiment according to the invention of the method of the type mentioned at the outset helps open further fields of use.

For instance, the method according to the invention can be used for the continuous masterbatching in the solids conveying range and for the grinding into powder of coarse-grained bulk material. Also, a combination of the two processes mentioned above is conceivable, i.e. a homogenization process of solids, which requires clearly less energy as compared with homogenization in the plastic phase.

Using the method according to the invention in reaction machines will moreover ensure efficient masterbatching of monomers and catalyst prior to the reaction in the incubation period.

Another advantage of the method according to the invention resides in that for instance pigments can be dispersed distinctly better during masterbatching.

In the following, the invention will be explained, based on diagrammatic illustration <sup>and drawings</sup> in which

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Fig. 1 is a representation of the "mean specific energy input",

Fig. 2 is a representation of the "material throughput and mean dwell time of the product in the extruder".

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10 Tests based on the method according to the invention were made on commercial two-shaft screw-type machines (two-shaft screw kneaders having tightly meshing screw shafts rotating in the same direction), the structure of the machine (screw geometry, mixing and kneading elements) being left as used so far for the respective plastics preparation process at customary speeds of rotation of 200 to 400 rpm.

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15 In the tests, use was made of screw speeds of rotation by far exceeding 1000 rpm, and surprisingly it was found that upon simultaneous increase of the induced torque density to 11 to 14 Nm/cm<sup>3</sup>, no substantial increase of material temperature occurred. Even with an increase of the material temperature (for instance PC > 350°C) to some unusually high melt temperature, there is no deterioration of the product, since the dwell times in the extruder are by far less than 10 s due to the method according to the invention.  
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Fig. 1 diagrammatically illustrates the context between the screw speed of rotation (shear rate) and the specific energy supplied for varying torque densities  $Md/a^3$ . Under the condition that the available torque is utilized,  
25 higher throughputs result while torque density increases (at a constant speed of rotation). Noticeably, reduced energy inputs and thus lower melt temperatures result from an increased torque density. On the other hand, an increase of the screw speed of rotation will generally lead also to increased



material throughput, however, at a given torque density, this throughput is connected with an increased energy input.

Fig. 2 illustrates the dependency of throughput and dwell time. It shows  
5 that while the throughput increases, the time during which the material is exposed to high temperatures is clearly reduced.

Tests carried out have shown that even a material temperature which, from experience so far, simply had to lead to reduced quality in the product will  
10 not mean quality impairment if the time of exposure is sufficiently short. However, sufficiently short dwell times can only be obtained by increased throughputs which, again, can only be realized by an increase of the possible torque, since otherwise, at a given (high) speed of rotation, the driving power of the machine will no longer be sufficient.

15 As can also be seen in Fig. 1, an increase of the speed of rotation within certain limits is possible even without an increase of the torque density. The maximum upper limit, adherent to every method, of specific energy input ( $e_{\text{specmax}}$  corresponds to the maximally permissible melt temperature  
20 without deterioration of the product at a given dwell time) restricts this speed of rotation.

As a rule, today's machines exhibit  $D_a/D_i$  values ranging from 1.4 to 1.6 and  $Md/a^3$  values between 5 and 10. Depending on the layout, the operating  
25 speeds of rotation range from 200 to 500 rpm, even to 600 rpm in exceptional cases.

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The throughput and the quality of the compounded product depend on the screw geometry utilized, on the speed of rotation and the maximum torque of the machine.

- 5 It is the object of every compounding job to obtain a homogenous final product - as a rule by incorporation of additives. The additives and any existing inhomogeneities must be dispersed in the machine and incorporated distributively. Dispersing particles requires more or less elevated shear stresses, which have to be imparted to the particles by way of the surrounding matrix. According to the equation

$$\tau = \eta * \bar{Y} \quad (1)$$

- 15 the shear stress  $\tau$  results from the viscosity  $\eta$  of the matrix medium and the shear rate  $\bar{Y}$  there forced on. Therefore, in addition to the melt temperature and the dwell time, the shear rate  $\bar{Y}$  [1/sec] is a decisive factor for the dispersing, mixing and homogenization grade of the processed product in the screw root filled with melt.

- 20 In a simplified consideration of the shear rate as a mean value from the quotient circumferential screw speed/spiral depth, the following applies (provided a 100 % degree of filling in the screw root):

$$\bar{Y} = \frac{v_u}{h} = \frac{D_a \cdot \pi \cdot n_s}{(D_a - D_f) / 2} \quad (2)$$

or

$$\bar{Y} = 2\pi \cdot n_s \cdot \frac{(D_a / D_f)}{(D_a / D_f) - 1}$$

The following is true for many processes:

The higher the shear rate, the higher the mixing, dispersing and homogenization grade. With today's state of extruder engineering, mean shear rates in the melt range of 20 1/s to 150 1/s and mean dwell times of the product in the entire screw range of 15 to 60 s are customary in standard preparation processes.

In conventional extruders, the mean shear rates are restricted upwards by the screw speed of rotation and the "volumetric ratio" designated by  $D_a/D_i$  as seen from the equation (2).

However, according to the equation

$$\bar{e}_{spec} = \frac{1}{\rho_s} \cdot \bar{\eta}_{(\dot{\gamma})} \cdot \bar{\dot{\gamma}}^2 \cdot \bar{t} \quad (3)$$

and

$$\bar{e}_{spec} = \frac{1}{\rho_s} \cdot \bar{\eta}_{(\dot{\gamma})} \cdot \bar{t} \cdot 4\pi^2 \cdot n_s \cdot \left[ \frac{(D_a / D_i)}{(D_a / D_i) - 1} \right]^2$$

higher values of specific energy input  $e_{spec}$  will result in the case of increasing shear rates, which again may lead to inacceptably high melt temperatures, since the temperature increase of the melt is computed from the equation  $\Delta T = e_{spec}/C_P$  ( $C_P$  = specific heat capacity). Combined with high average dwell times of the product in the extruder, a high shear rate may also lead to quality reducing deterioration of the product (thermal decomposition or cross-linking).

In twin-screw extruders rotating in the same sense and having screw speeds of rotation in the range of 600 to 3000 rpm accompanied with the increase of the induced torque density to 11 to 15 Nm/cm<sup>3</sup>, quality increasing mean shear rates of up to 1000 1/s and simultaneous reduction of the duration of action of temperature peaks in the product can be realized by the method according to the invention.

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Symbols Used:

	$\bar{e}_{\text{spec}}$	mean specific energy supplied [kWh/kg]
5	$\bar{t}$	mean dwell time of the product in the extruder [s]
	$\rho$	melt density [kg/m <sup>3</sup> ]
	$\bar{Y}$	mean shear rate [1/sec]
10	$\bar{\eta}$	mean dynamic viscosity [Pa sec]
	$D_a$	screw outer diameter [mm]
15	$D_i$	screw inner diameter [mm]
	$\bar{h}$	spiral depth, mean value
	$n_s$	screw speed of rotation [min <sup>-1</sup> ] ([s <sup>-1</sup> ])
20	$M_d$	shaft torque, related to 1 shaft [Nm]
	$a$	center distance of axes of the screw shafts [cm]
25	$v_u$	circumferential speed of the screw shafts [m/s]
	$M_{d/a}$	torque density, related to 1 shaft [Nm/cm <sup>3</sup> ]
	$\bar{\tau}$	shear stress [Nm/mm <sup>2</sup> ]
30	$c_p$	specific enthalpy [kJ/kg*K]
	$m$	material throughput [kg/h]
35	$\Delta T$	material temperature increase [K]

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